

Steel Structures and Bridges 2012

Bending Moments due to Elastic Buckling Mode Applied as Uniform Global and Local Initial Imperfection of Frames

 I. Baláz^{a*} and Y. Koleková^b

^aDepartment of Metal and Timber Structures, ^bDepartment of Structural Mechanics,
Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11, Bratislava, SK-81368, Slovak Republic

Abstract

The verification of the stability of frames or their parts carried out considering imperfections and second order effects accounted for by global analysis. The shape of the elastic critical buckling mode $\eta_{cr}(x)$ of the structure is applied as a unique global and local initial (“ugli”) imperfection $\eta_{ugli}(x) \equiv \eta_{init}(x)$ with amplitude $\eta_{0,ugli,m}$ proposed by Professor Chladný. Detailed description of the procedure of iterative calculation based on Chladný’s method but different from it may be found in [1]. The graphical interpretation of the results proposed by the authors and numerical example for two-hinged portal frame with uniform cross-sections and uniform axial compression forces based on [1] are presented.

© 2012 Published by Elsevier Ltd. Selection and review under responsibility of University of Žilina, FCE, Slovakia.

Open access under [CC BY-NC-ND license](https://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: Frame; Stability; Imperfection; Buckling Mode; Bending Moment; Resistance; Steel; Aluminium; Eurocodes.

1. Introduction

According to Eurocodes [2] and [3], see clause 5.2.2(5)a), if second order effects in individual members and relevant member imperfections (see 5.3.4) are totally accounted for in the global analysis of the structure, no individual stability check for the members according to 6.3 is necessary. According to 5.3.2(11) as an alternative to 5.3.2(3) and 5.3.2(6) the shape of the elastic critical buckling mode η_{cr} of the structure may be applied as a unique global and local initial (“ugli”) imperfection. The amplitude of “ugli” imperfection may be determined from:

$$\eta_{ugli}(x) \equiv \eta_{init}(x) = \eta_{0,ugli,m} \eta_{cr}(x), \quad \eta_{0,ugli,m} = \frac{N_{cr,m} \cdot e_{0,d,m}}{EI_m |\eta_{cr,m}''|} = \alpha_{cr} \cdot \frac{N_{Ed,m} \cdot e_{0,d,m}}{|M_{\eta_{cr,m}}|} \quad (1)$$

* Tel.: +0-421-2-59274379; fax: +0-421-2-52494116.

E-mail address: ivan.balaz@stuba.sk

$$e_{0,d,m} = e_{0,k,m} \cdot \frac{1 - \chi_m \cdot \bar{\lambda}_m^2}{1 - \chi_m \cdot \bar{\lambda}_m^2} \cdot \frac{\gamma_{M1}}{\gamma_{M1}} \quad (2)$$

$$e_{0,k,m} = \alpha_m \cdot (\bar{\lambda} - 0,2) \cdot \frac{M_{Rk,m}}{N_{Rk,m}}, \quad \text{for } \bar{\lambda}_m > 0.2 \quad (3)$$

The formulae (1, 2, 3) were derived by Chladný, who described details of his method and published numerical examples in [4]. The way of calculation proposed by Baláž, I. in [1] used in this paper was used also in PhD thesis written by Kováč, M. [5].

Chladný developed his method with the aim to derive a formula for the lateral forces acting on U-frames of open truss bridges in [6] and in [7]. He showed there the importance of the curvature of the initial imperfection. The results were used in Czechoslovak Bridge Standard ČSN 73 6205: 1984, cl. 39. See also Chladný's paper [8].

In the year 2000 proposed Chladný his method in more generalized form for Eurocode 3, and it was the first time accepted in the draft of prEN 1993-1-1 (edition 5 June 2002). His contribution is acknowledged in the publication [9], see there item [52]. Chladný derived the formula for $e_{0,d}$ and is the author of the method given in [2], clause 5.3.2(11). Baláž helped with some improvements (e.g. he introduced absolute values in formulae) and with formulation and submitting of proposals to CEN/TC 250 subcommittees SC 3 and SC9. Chladný later generalized the method also for non-uniform cross-sections and non-uniform compression forces. This generalization is used in [3], clause 5.3.2(11) and in [10]. Chladný applied his method in the design of bridges in practice, e.g. in design of basket handle arch type Apollo bridge in Bratislava, Pentele bridge in Dunaújváros and in investigations of continuous truss bridges. He further modified his method to be convenient for basket handle arch type bridges in the National Annex [11].

The procedure published in [1] is applied in numerical example and used for the drawing of graphical interpretation, which is valid for constant normal force distribution and uniform cross-section (Fig. 1, 2 and 3).

2. Flexural buckling resistance of frames with uniform members and compression normal forces

Flexural buckling resistance of the frame, which consists of members with variable cross-sections, with any boundary conditions, supports and/or variable foundation and under variable axial forces may be verified by the following condition

$$\left(\frac{N_{Ed}(x)}{N_{Rd}(x)} + \frac{M_{Ed,ugli}^{II}(x)}{M_{Rd}(x)} \right)_{max} \leq 1 \quad (4)$$

The location of the critical cross-section „ m “ is generally not known, because it depends on the location of maximum of the sum of two functions in the left side of the condition (4). The value of the second term in (4) depends on the characteristics of the critical cross-section „ m “. The location of the maximum of the first function in (4): $N_{Ed}(x)/N_{Rd}(x)$ usually does not coincide with the location of maximum of the second

function in (4): $M_{Ed,ugli}^{\prime\prime}(x)/M_{Rd}(x)$, which is given by location of max. value of curvature $|\eta_{cr}^{\prime\prime}(x)|_{max}$.

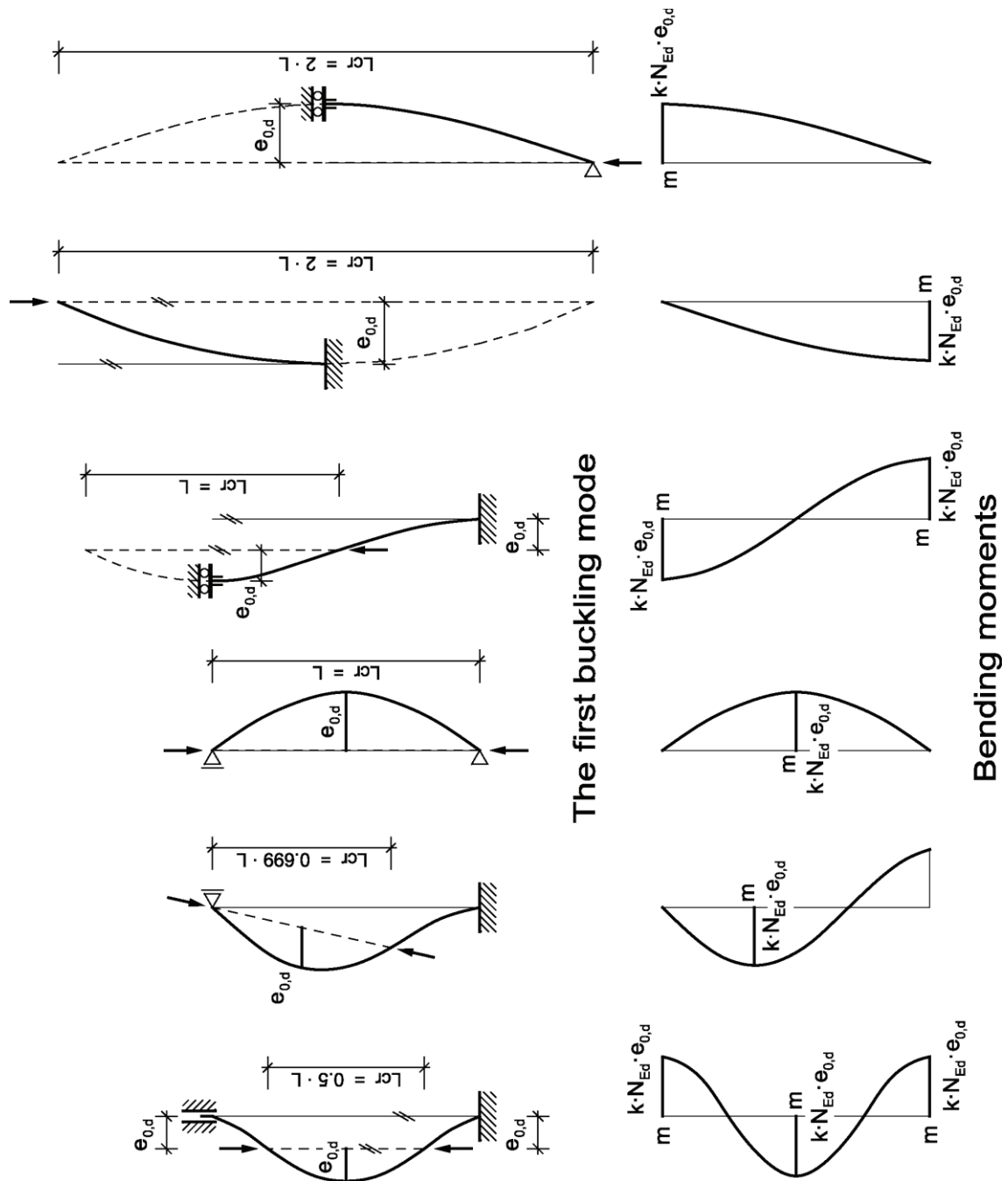


Fig. 1. Shape of elastic buckling mode applied as "ugli" imperfection. Bending moments due to "ugli" imperfection and location of "m".

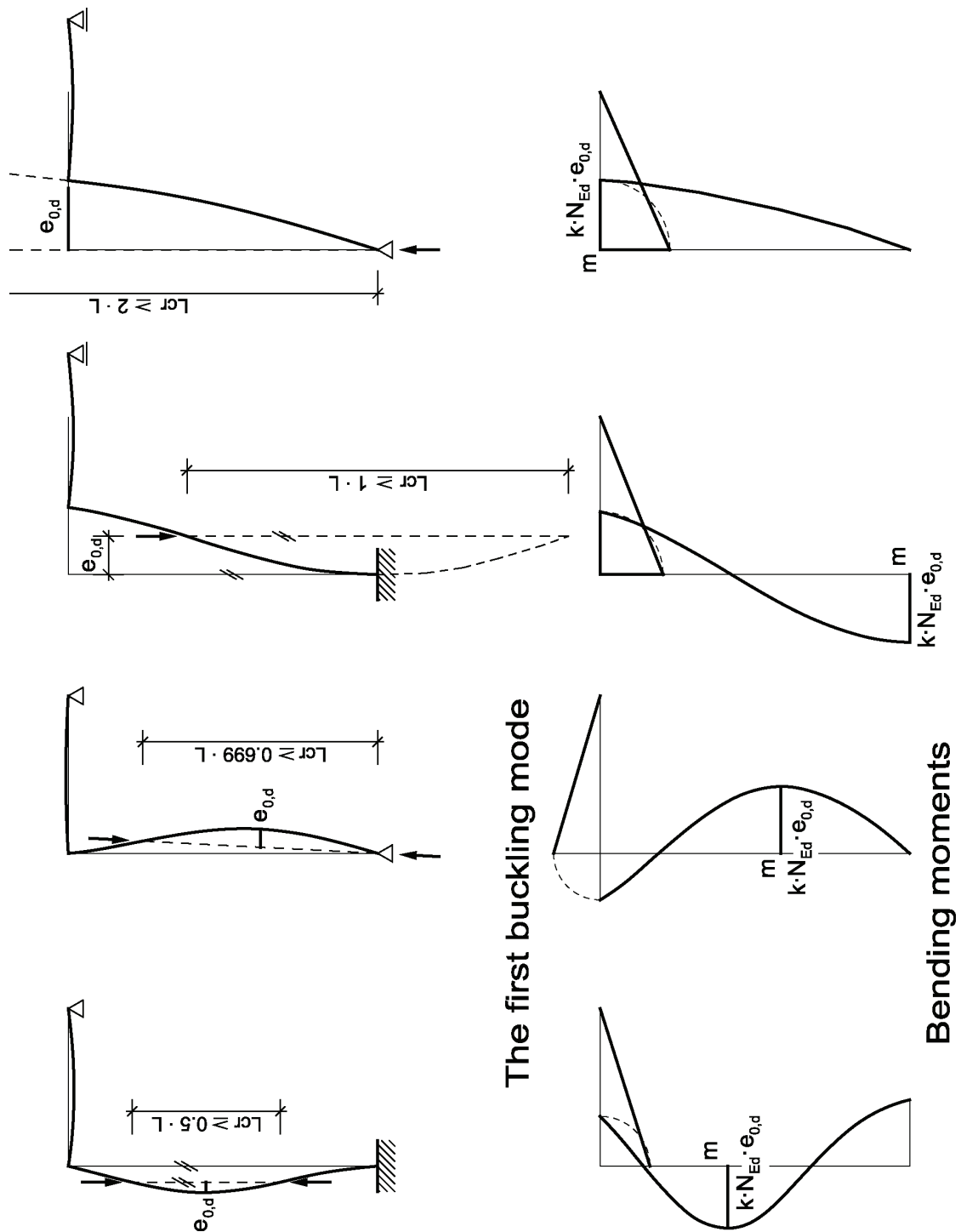


Fig. 2. Shape of elastic buckling mode applied as "ugli" imperfection. Bending moments due to "ugli" imperfection and location of "m".

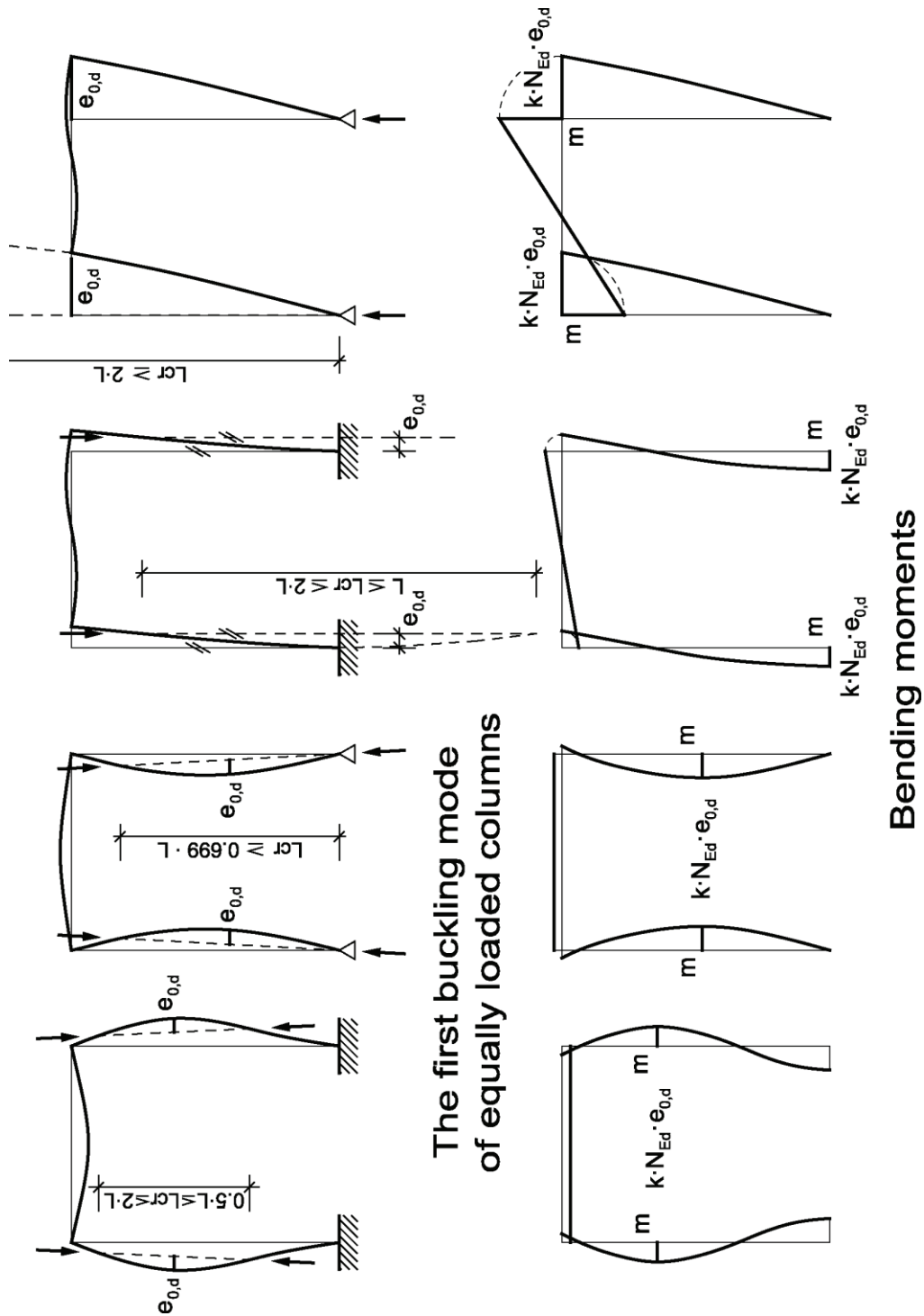


Fig. 3. Shape of elastic buckling mode applied as “ugli” imperfection. Bending moments due to “ugli” imperfection and location of “m”.

Generally it is therefore necessary to use iterative calculation. In the special case, when $N_{Ed}(x)/N_{Rd}(x)$ is constant, and the cross-section is uniform, the location of critical cross-section „m“ is determined by the location of $|\eta''_{cr}(x)|_{max}$. The locations of critical points „m“ for 14 special cases are shown in Fig.1, 2 and 3.

2.1. Numerical example

The two-hinged portal frame [12], Fig.42 with columns HEB 260, $h = 4,6\text{ m}$ and beam HEA 360, $L = 9,4\text{ m}$ is analyzed. Fig. 43 and results on page 305-306 in [12] are incorrect. The correct results for the class 1 or 2 cross-section may be obtained very easy by proposed procedure as follows (details of the procedure see in [1]):

$$A = 11800\text{ mm}^2, W_{pl,y} = 1282 \cdot 10^3\text{ mm}^3, f_y = 355\text{ MPa}, \gamma_{M1} = 1,0, \alpha = 0,34, N_{Ed} = 620\text{ kN} \quad (5)$$

$$N_{Rk} = 4189\text{ kN}, M_{Rk} \equiv M_{pl,y,Rk} = 455,1\text{ kNm}, \alpha_{cr} = 4,45, k = \alpha_{cr}/(\alpha_{cr} - 1) = 1,29, \bar{\lambda} = 1,23 \quad (6)$$

$$\chi = 0,461, L_{cr} = 2,302 \cdot h, \eta_{ugli,m} = e_{0,d} = 38,14\text{ mm}, M_{II,Ed,imp} = k \cdot N_{Ed} \cdot e_{0,d} = 30,506\text{ kNm} \quad (7)$$

The results obtained by computer program IQ 100 (TU Vienna) show good agreement (see last frame in Fig.3):

$$\eta_{ugli,m} = e_{0,d} = 38,125\text{ mm}, M_{II,Ed,imp} = k \cdot N_{Ed} \cdot e_{0,d} = 30,5054\text{ kNm} \quad (8)$$

Acknowledgements

Authors acknowledge support by the Slovak Scientific Grant Agency under the contract No. 1/1101/12.

References

- [1] Baláž, I.: Determination of the flexural buckling resistance of frames with members with non-uniform cross-section and non-uniform axial compression forces, in: *Zborník z XXXIV. aktívu pracovníkov odboru OK so zahraničnou účasťou „Teoretické a konštrukčné problémy ocelových a drevených konštrukcií a mostov“*. Pezinok, 2008, pp.17-22.
- [2] EN 1993-1-1 Eurocode 3: Design of Steel Structures. Part 1-1: General Rules and Rules for Buildings, CEN Brussels, 2005.
- [3] EN 1999-1-1 Eurocode 9: Design of Aluminium Structures. Part 1-1: General Structural Rules, CEN Brussels, 2007.
- [4] Baláž, I., Ároch, R., Chladný, E., Kmet', S., Vičan, J.: Design of Steel Structures According to Eurocodes STN EN 1993-1-1:2006 and STN EN 1993-1-8:2007. Slovak Chamber of Civil Engineers (SKSI) Bratislava, 1st Edition 2007, 2nd Edition 2010.
- [5] Kováč, M.: *Buckling resistance of metal members and frame structures. Application of new Eurocode methods*. PhD thesis. Faculty of Civil Engineering. Slovak University of Technology in Bratislava, 2010. Supervisor: I. Baláž.
- [6] Chladný, E.: *Nosnosť tlačných pásov otvorených mostov (Buckling resistance of compressed chords of open truss bridges)* PhD thesis, SVŠT (Slovak Technical University of Technology) Bratislava, 1958.
- [7] Chladný, E.: *Vzper pružne podopretých tlačných prútov (Buckling of elastically supported compressed members)* Habilitation thesis, SVŠT Bratislava. 1974.
- [8] Chladný, E.: Nachweise der Querrahmen von Fachwerktrogbrücken mit offenem Querschnitt nach EC 3-2 und STN 73 6205. In: *Entwurf, Bau und Unterhaltung von Brücken im Donaauraum*. Bauingenieur Sonderpub., Springer-VDI-Verlag, Düsseldorf. 1998.
- [9] Sedlacek, G., Eisel, H., Hensen, W., Kühn, B., Paschen, M.: Leitfaden zum Fachbericht DIN 103. Stahlbrücken. Ausgabe März 2003. Ernst & Sohn, A Wiley, 1974.
- [10] STN EN 1993-1-1/NA Design of steel structures. Part 1-1: General rules and rules for buildings. Slovak National Annex. SÚTN Bratislava, 2007.
- [11] STN EN 1993-2/NA Design of steel structures. Part 2: Steel Bridges. Slovak National Annex. SÚTN Bratislava, 2009.
- [12] Lindner, J. – Heyde, S.: *Schlanke Stabtragwerke*. Stahlbau Kalender 2009, pp.305-306.